Mobility for High Effective Field in Double-Gate and Single-Gate SOI for Different Substrate Orientations

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1. Abstract

Low-field mobilities for (100) and (110) substrate orientations in single-gate (SG) and double-gate (DG) operation modes are compared. It is argued that for the same gate voltage twice as high carrier concentration in DG ultra-thin body (UTB) SOI as compared to the SG mode leads to a higher relative occupation of primed subband ladder for (100) substrate orientation. Efficient scattering in primed subbands overpowers the mobility enhancement due to the volume inversion in DG and leads to a lower DG mobility at high effective fields as compared to that for SG UTB SOI.

2. Method and Results

Mobility in UTB silicon films is the subject of intensive experimental [1,2] and theoretical studies [3-5] due to the superior potential of DG SOI FETs for scaling. Mobility in DG should be enhanced due to the volume inversion in UTB Si films. Recent experiments [2] have confirmed that the DG mobility is indeed higher than the one in SG operation for (110) SOI. (100) SOI DG mobility is, however, inferior to the SG one at high carrier concentrations [1,2]. It was suggested in [2] that substantially smaller splitting between the lowest primed and unprimed subbands in DG is responsible for the higher occupation of subbands and for the mobility lowering at high effective fields. In order to verify this suggestion, we have carried out Monte Carlo simulations for (110) and (100) UTB SOI in both SG and DG modes.

Degeneracy effects for carriers in UTB SOI, especially at high effective fields, are of a major importance. We have used a Monte Carlo algorithm developed for small signal response calculations [6]. This method is formally exact in the limit of small driving fields, allowing accounting for degeneracy effects and non-parabolic band structures, and is perfectly suited for the low-field mobility calculations. Since we are mostly interested in mobility at high carrier concentrations, Coulomb scattering is neglected. For simplicity we consider only electron-phonon interactions and surface roughness scattering, which is assumed to be equal and uncorrelated at opposite interfaces.

Fig. 1 shows the mobility dependence on carrier concentration N_S for several T_{SOI} values for (100) SOI in SG mode. Good agreement with previous simulations [4] is achieved. Fig. 2 shows the mobility for both SG and DG operation modes for (100) SOI together with experimental data as a function of N_S (SG) and $N_S/2$ (DG). Although at small concentrations the DG mobility tends to be slightly higher, at high N_S and for thin T_{SOI} it is significantly degraded as compared to the SG mobility, in qualitative agreement with the experimental data. Note that additional scattering mechanisms must be incorporated in order to achieve a better quantitative agreement [5].

Fig. 3 displays the mobility in <001> direction for (110) SOI, in DG and SG modes. The calculated DG mobility is superior in the whole range of N_S, in agreement with the experiment [2]. This behavior is consistent with the volume inversion hypothesis [3]. Contrary to the hypothesis, the (100) DG mobility is lower than the SG mobility at high N_S. Fig. 4 displays correlations between the (100) DG mobility degradation and the primed subband occupation increase. Scattering in primed subbands suppresses the mobility enhancement due to the volume inversion in DG.

It was suggested [2] that the higher occupation of the primed ladder in DG is due to a substantially smaller intersubband splitting as compared to the SG. We have found that in UTB SOI this effect is relatively small: the subband structure is determined by T_{SOI} wall quantization and is similar in both DG and SG mode. Higher occupancy of primed subbands in DG mode is due to a twice as large carrier concentration than in the SG case, as illustrated in Fig. 5. Fig. 6 displays the relative contributions of two mechanisms to the occupancy of primed subbands in DG mode.

3. Conclusions

Low-field mobility is theoretically predicted for (100) and (110) UTB SOI. It is shown that twice as high carrier concentration in DG mode leads to a higher occupation of primed ladder for (100) UTB SOI and lower DG mobility at high effective fields as compared to its SG counterpart.

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References

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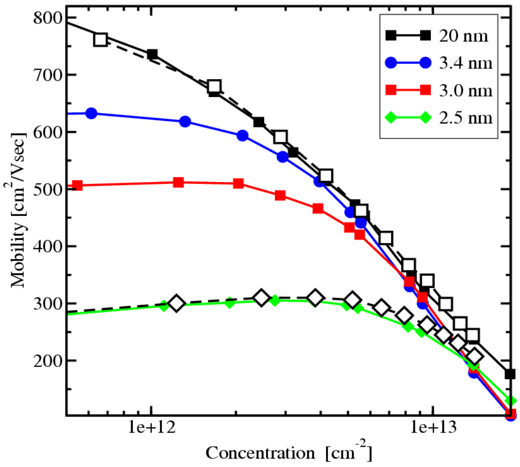

Fig.1: *Mobility dependence on concentration for different Si thicknesses, in SG operation. Results of simulations* [4] *are shown for comparison (open symbols).*

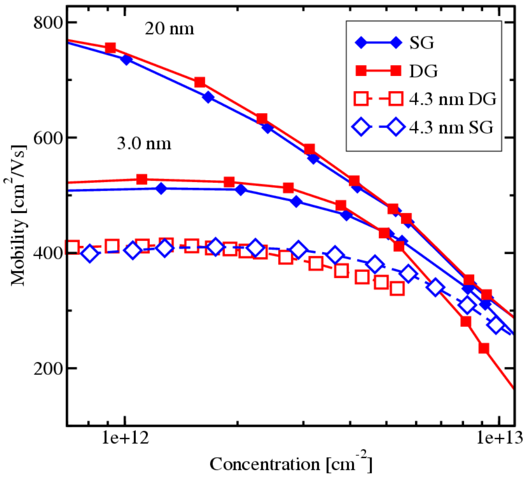

Fig.2: *Mobility for SG (diamonds) and DG SOI (squares) at (100) substrate. For high concentrations, the DG mobility becomes lower than the SG mobility, in qualitative agreement with experiment* [1] *(open symbols).*

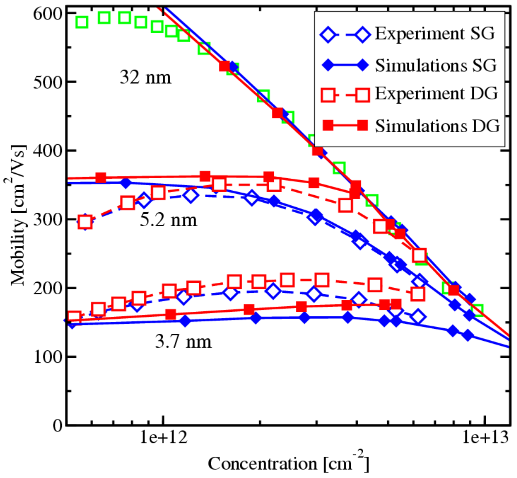

Fig.3: *Mobility at (110) substrate in <001> direction, for different silicon thicknesses. Mobility in DG operation is higher for all N_S, in qualitative agreement with recent experiment* [2].

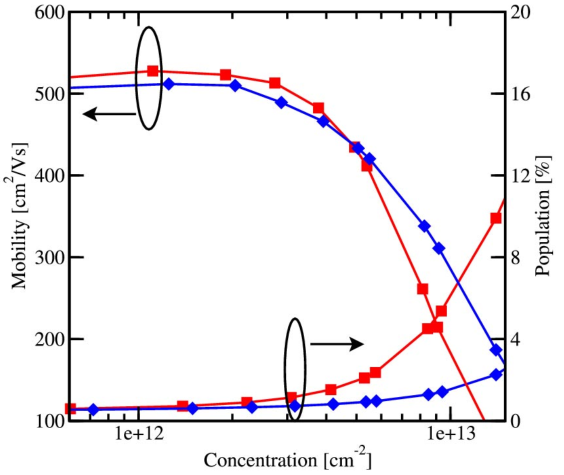

Fig.4: *Mobility and primed subband occupation plotted as function of N_S for SG and $N_S/2$ for DG (100) SOI with T_{ox} = 3nm. Strong correlation between mobility degradation and high occupation of primed subband with efficient scattering is seen..*

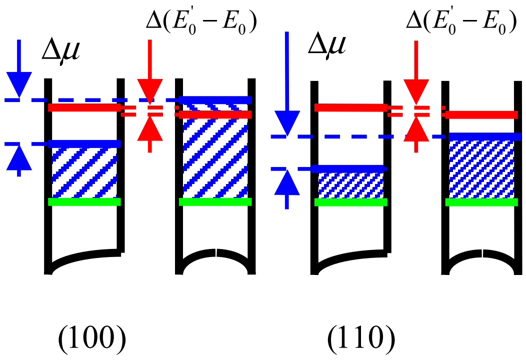

Fig.5: *Schematic band structure in SG (left) and DG (right) UTB SOI. Subband energies are determined by Si film wall quantization and are approximately the same in SG and DG, for similar gate voltages. Higher occupation of primed subands in (100) DG is due to doubled total concentration, as compared to SG, and low density of states in the unprimed subband.*

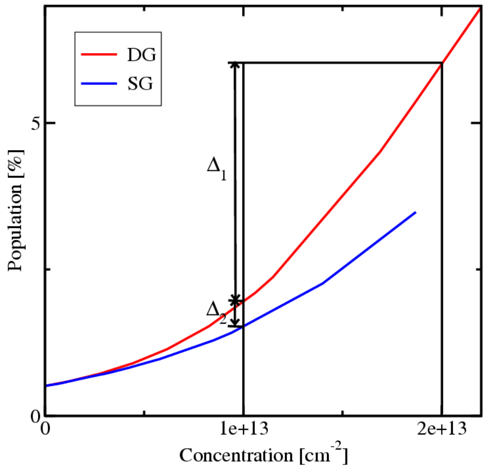

Fig.6: *Primed subband occupation plotted as a function of N_S for both SG and DG SOI. Relative contribution Δ_2 to primed subband occupation due to difference in bandstructure [2] in DG is small in comparison to the contribution Δ_1 due to doubled concentration.*